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MATERIAL ANALYSIS OF AUSTEMPERED DUCTILE IRON

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13. ABSTRACT (Maximum 200 words)

A materials analysis was performed on a sample of austempered ductile iron (ADI). This material was supplied in the heat-treated condition by a commercial producer. ADI is being examined as a potential alternate material to be used in the manufacture of muzzle brakes and other candidate weapon components. The analysis included mechanical property determination, chemical composition determination, metallographic examination, and scanning electron microscopy. The mechanical properties obtained were compared to the requirements specified on the 155-mm M284 muzzle brake drawing and the military casting specification MIL-B-12253. Based on the analysis, the ADI material examined would not be suitable as an alternate material for the muzzle brake. Furthermore, the results of the evaluation suggest that the material may not have been properly heat treated for this particular application.

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TABLE OF CONTENTS

TABLES

LIST OF ILLUSTRATIONS

INTRODUCTION

Advanced Engineering Branch of Benet Laboratories received from Infantry and Artillery Cannon Branch, a piece of austempered ductile iron (ADI), weighing approximately 30 pounds, for material characterization and evaluation. This material is being tested as a potential alternate material in the manufacture of muzzle brakes. Some background and theory on the austempering process and ADI are provided below.

BACKGROUND

Austempering is an isothermal heat treatment for ferrous alloys in which a part is (1) quenched from the austenitizing temperature at a rate fast enough to avoid formation of ferrite or pearlite, and (2) held at a temperature above martensite-start (Ms) until transformation to bainite is complete. A typical heat treatment sequence follows:

- Heat to a temperature within the austenitizing range, usually 1450° to 1600°F
- Quench in a salt bath maintained at a constant temperature, usually 500° to 750°F
- Allow isothermal transformation to bainite in this bath
- Cool to room temperature, usually in still air (ref 1)

Austempering of steel and hardenable grades of cast iron offers several potential advantages over conventional castings:

- Increased ductility or notch toughness at a given hardness
- Reduced distortion which lessens subsequent machining time, stock removal, and cost
- Shortest overall time cycle to through-harden within the range of 35 to 55 Rockwell C hardness (HRC), with resulting savings in energy and capital investment (ref 1).

There is the misconception that ADI is commonly thought of as a specialty steel with graphite particles in it. In steel, there is a fixed carbon content. In ductile iron, however, because of the graphite nodules and silicon content, the matrix has a variable carbon content. This "carbon mobility" is what makes ductile iron differ from steel. The matrix structure in ADI contains 10 to 30 percent austenite, but it is thermally stable to more than -400°F. The austenite in ADI is "retained" to the extent that it has not experienced a phase transformation, but it is more appropriately called "carbon enriched stable austenite" in the matrix (ref 2).

ADI is a high strength, wear resistant, heat treated, <u>cast iron</u> material. It can develop more than double the strength of conventional ductile cast iron for a given level of ductility.

The austempering cycle consists of heating the part in a controlled environment to an austenitizing temperature between 1450° and 1600°F. The part is held at temperature for a time sufficient to saturate the austenite with carbon. It is then cooled at a rate sufficient to avoid the formation of pearlite and other high temperature transformation products, to the appropriate austempering temperature between 500° and 750°F. The part is held at the austempering temperature for a time sufficient to complete transformation and produce the desired properties (ref 2).

ADI transformed in the 700°F range exhibits relatively high ductility and impact strength at a tensile strength of about 150,000 psi. ADI transformed at 500°F exhibits wear resistance comparable to case-hardened steel and a tensile strength in excess of 222,000 psi. This material exhibits a wide range of properties. The American Society for Testing and Materials (ASTM) has nominated five grades of ADI for inclusion in a new ASTM standard. These grades are summarized in Table 1.

Finally, austempering has the advantage over conventional quenching and tempering in that bainite transformation takes place isothermally at a relatively high temperature so the transformation stresses are very low. This results in an absolute minimum of distortion and practically complete assurance that quench cracking will not occur (ref 3).

PROCEDURE

Our analysis consisted of the following:

- Mechanical property testing
  - Tensile
  - Charpy Impact Toughness
  - Hardness
  - Fracture toughness (K_{Ic})
- Chemical analysis
- Metallographic examination
- Scanning electron microscopy (SEM)

Mechanical Property Testing

As shown in Table 2, the mechanical property results did not meet the requirements specified on the muzzle brake drawing or the military specification. Specifically, the yield strength and Charpy values were far below specification. There was no recorded data for the percent reduction in area or the percent elongation because the tensile bars fractured outside the extensometer.

Table 1 depicts the proposed ASTM standards for ADI. The material we tested met Grade 1 requirements for hardness and strength, however, impact toughness was tested at a different (lower) temperature.

Chemical Analysis

The chemical analysis is outlined in Table 3. Chemical composition requirements of a 155-mm M284 muzzle brake include sulfur and phosphorous at weight percent 0.015 maximum. Benet's results showed the sulfur under this limit and the phosphorous slightly over, but within experimental error.

Metallographic Examination

The as-polished samples revealed graphite nodules in the matrix. These nodules are typical constituents found in ductile cast irons. Figures 1 and 2 depict this feature. The microstructure, etched in 2 percent Nital, consisted of a mixture of tempered bainite and martensite, as shown in Figure 3. This structure is normally stronger, but less ductile than ferritic or pearlitic ductile iron.

Scanning Electron Microscopy

SEM of the fracture surface revealed graphite nodules randomly dispersed on the surface (see Figure 4). In addition, cleavage facets were observed on the surface indicative of a brittle fracture mode. These features are illustrated in Figures 5 and 6.

CONCLUSION/RECOMMENDATION

Based on our results, this sample of ADI would not be suitable for the manufacture of muzzle brakes. The mechanical property values we obtained did not meet requirements for either the muzzle brake drawing or the casting specification. Although we do not know the details of the heat treatment process, it is evident that the material does not meet the requirements of the muzzle brake casting. Furthermore, this material does not comply with the requirements of the proposed standard. The mechanical property evaluation and SEM characterizations show the sample to be brittle and suggest that it was not properly heat treated. Therefore, we recommend that Benet Laboratories perform experimental heat treatments on this type of material so that we can properly test and appraise this material.

REFERENCES

1. Keough, John R., "Recent Developments in Austempered Ductile Iron (ADI)," Oshkosh, WI, 19 October 1988.

2. *Metals Handbook*, Volume 8, American Society for Metals, Metals Park, OH, 1964, p. 56.

3. *The Making, Shaping and Treating of Steel*, U.S. Steel, Pittsburgh, PA, 1971, p. 1103.

Table 1. The Proposed Five ASTM Standard ADI Grades

Grade	Tensile Strength**		Yield Strength**		% Elongation**	Impact Energy*		Typical Hardness	HRC
	(MPa)	(Ksi)	(MPa)	(Ksi)		(J)	(ft-lbs)	BHN (B.I.D.)	
1	850	124	550	80	10	100	74	269-321 (3.4-3.7)	28-35
2	1050	153	750	109	7	80	59	302-363 (3.2-3.5)	33-39
3	1200	175	900	131	4	60	45	341-444 (2.9-3.3)	37-47
4	1400	204	1100	160	1			388-477 (2.8-3.1)	
5	1600	233	1300	189				444-555 (2.6-2.9)	

* Tested at 22°C ±7°C.
** Values represent minimums.

Table 2. Mechanical Properties

	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	% Elongation	% Reduction in Area	Charpy V-Notch (-40°F) (ft-lbs)	K_I (Ksi $\sqrt{in.}$)	HRC
Sample 1	93.6	126.9			3.0	71.2	28
Sample 2	94.8	132.9			2.5	75.3	28
Sample 3	96.9	129.9			2.5		29
WTV F30193 (155-mm M284 Muzzle Brake)	140 min 160 max						
MIL-B-12253D Casting Spec.				23 min	18 min		
ASTM Grade 1 (Proposed)	80 min	124 min	10 min		74 (at 44°F)		28-35

Table 3. Chemical Composition

Element	Benet	Required (Per WTV F30193)
Carbon	3.51	
Sulfur	0.007	0.015 max
Silicon	2.39	
Phosphorous	0.016	0.015 max
Manganese	0.191	
Molybdenum	0.225	
Copper	0.67	
Titanium	0.007	

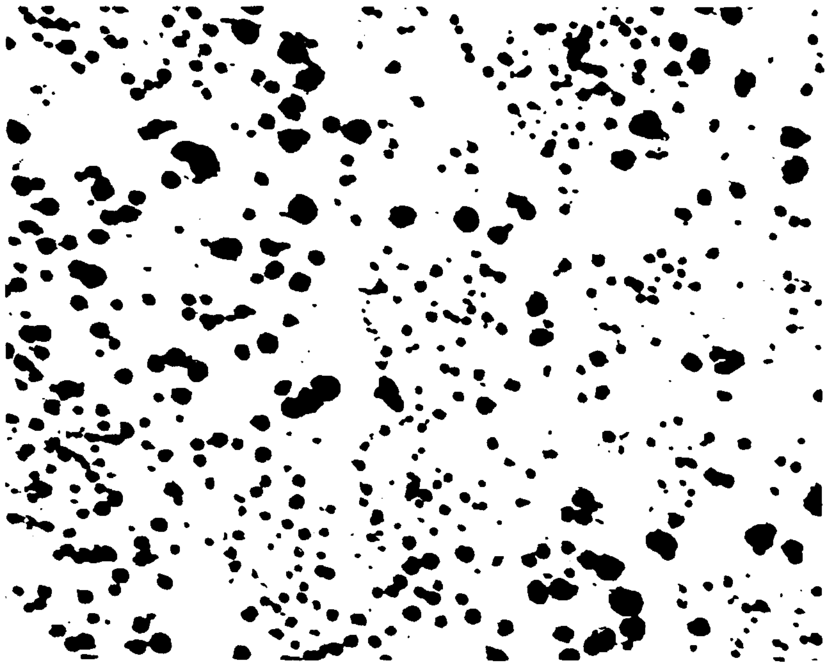

Figure 1. As-polished sample revealing graphite nodules, at 50X.

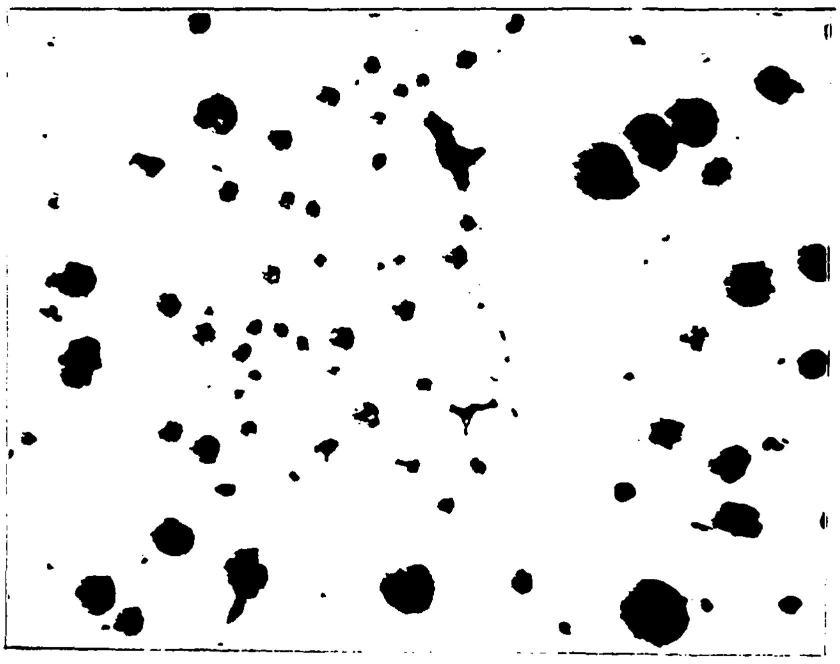

Figure 2. Higher magnification of Figure 1, at 100X.

Figure 3. Microstructure consisting primarily of tempered bainite, at 2000X.

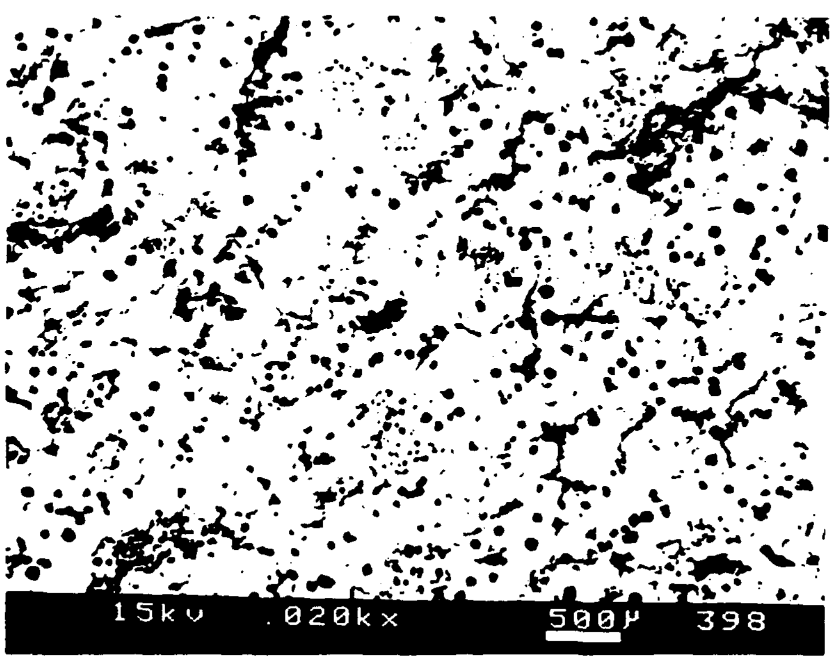

Figure 4. Fractograph depicting graphite nodules randomly dispersed on the surface, at 20X.

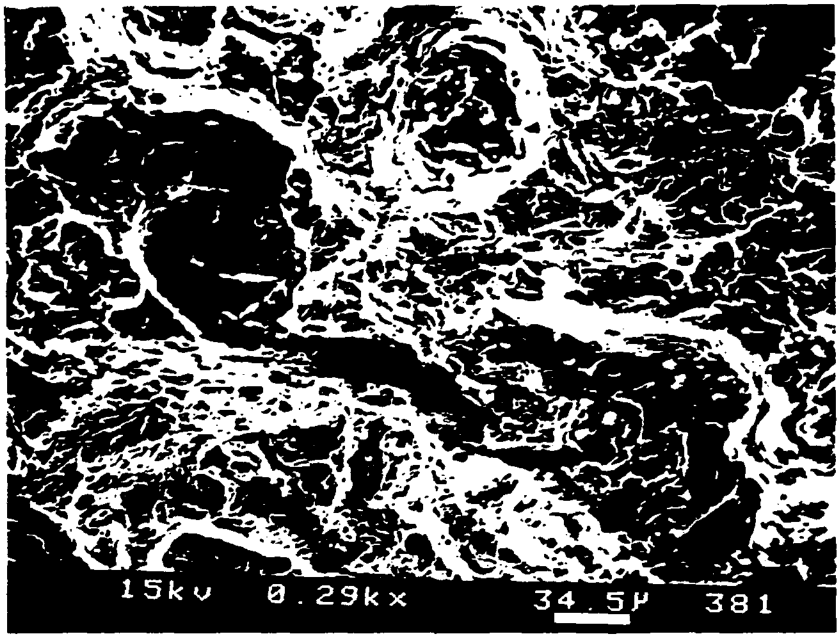

Figure 5. Fractograph depicting cleavage indicative of brittle fracture mode, at 290X.

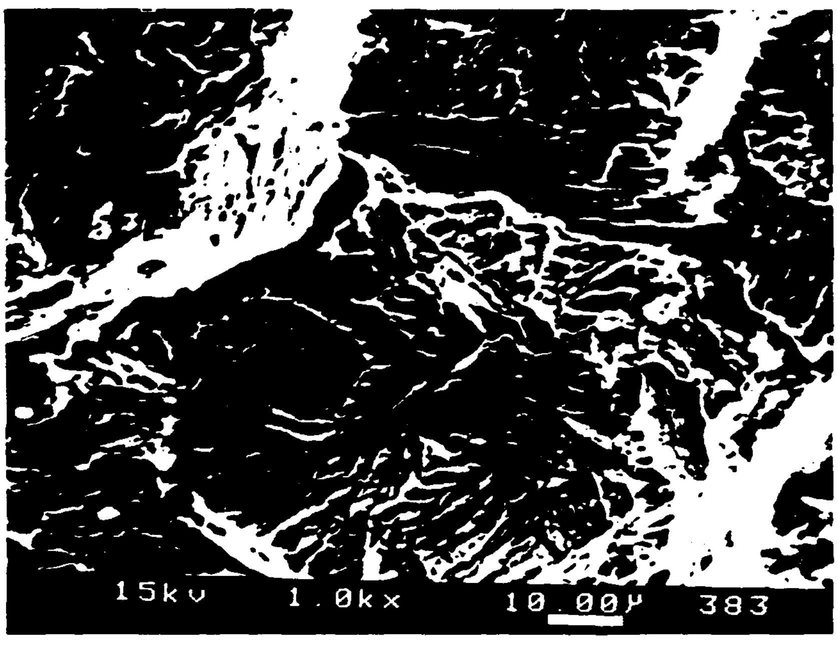

Figure 6. Higher magnification of Figure 5, at 1000X.

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